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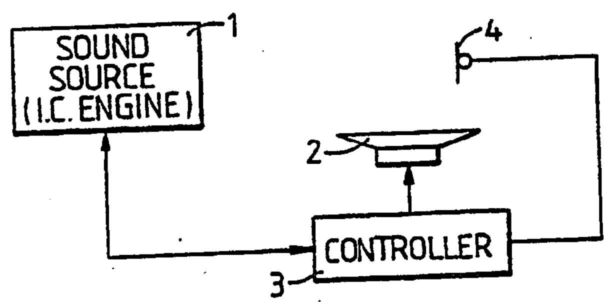

(57) Abstract

Primary vibrations (N), e.g. acoustic noise or vibration from a source thereof such as a motor, are cancelled by secondary vibrations (C) produced by an actuator (2) driven by a controller (3) that is responsive to an error signal (E) detected by a detector (4) and representative of the residual or difference between the primary and secondary vibrations. The controller samples the error signal (E) during successive sampling periods determined by a synchronising signal (syn) taken from the motor. The secondary vibrations C_{n+1} for a sampling period n + 1 are determined as follows: $C_{n+1} = C_n - \mu E_n SGN[1/\overline{H}]$, where C_n represents the secondary vibrations produced during a preceding sampling period (n); E_n represents the detected error signal for said preceding period n, H represents the transfer coefficient between the actuator (2) and the detector (4) and μ is a scaling factor where $0 \leqslant \mu \leqslant 1$. The apparatus is in one embodiment configured as an add-on unit for a personal computer (PC) including circuit board which fits into an expansion slot of the PC.

ACTIVE NOISE REDUCTION

DESCRIPTION

This invention relates to apparatus for cancelling vibrations, which may be gas, liquid or solid-borne, by nulling primary vibrations, at least in part, with specially generated cancelling or secondary vibrations.

It has been proposed to cancel repetitive noise produced by e.g. an internal combustion engine, by generating cancellation noise with a controller such that the cancellation noise at least in part cancels the repetitive noise produced by the engine. In order to maintain the amplitude and phase of the cancellation noise in opposition to the noise itself, a detector in the form of a microphone is used to determine the residual noise or error between the cancellation noise and the noise itself. The error signal is used to control the output of the controller in accordance with a predetermined algorithm for maintaining a desired cancellation condition. Also, in order to allow the system to track changes in fundamental frequency of the

noise, a synchronisation sensor is utilised to provide an indication of the fundamental frequency of the noise e.g. from the speed of rotation of the engine. An example of such an arrangement is disclosed in US Patent 4 417 098 (Chaplin et al). The apparatus may operate in a number of different frequencies each comprising a different harmonic of the fundamental frequency so as to produce cancellation over a broad frequency band.

The algorithm for the controller operates so that samples of the error signal are compared with one another and the output of the controller is modified in accordance with the algorithm to produce a iterative reduction of the error signal. However, as will be described in more detail hereinafter, the iterative technique utilised has a tendancy in conditions close to cancellation, to become unstable as a result of the error signals becoming small, so that the differences between successive error samples can contain a large percentage error that can drive the controller to produce a uncancelled condition.

In accordance with a first aspect of the invention, there is provided improved apparatus for cancelling vibrations wherein the controller is operated in accordance with an improved algorithm that is less prone to drive the apparatus out of the cancelled condition.

In accordance with a second aspect of the invention, there is provided improved noise cancellation apparatus implemented by means of an add-on unit for a personal computer (PC). The apparatus is conveniently embodied as a first circuit board for insertion into the expansion slot of a conventional PC, and a second circuit board driven by the first board and conveniently external to the PC, the second board including an output for a cancellation noise signal, an input for a noise error signal and an input for an external synchronisation signal. Also, software is provided, typically on a floppy disc, to configure the PC processor to perform cancellation in accordance with a predetermined algorithm.

The apparatus may also include means for producing demonstration noise waveforms to be cancelled. Such waveforms may simulate the noise produced by e.g. a helicopter or a motor vehicle so that the apparatus can be used as a demonstration device for active noise cancellation.

In order that the invention may be more fully understood an embodiment thereof will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram of an apparatus according to the invention for the active cancellation of repetitive noise from a machine;

Figure 2 is a schematic functional diagram for the signals discussed in relation to Figure 1;

Figure 3 is a schematic block diagram of an example of the invention for use with a personal computer; and

Figure 4 is a more detailed schematic block diagram of first and second circuit boards used in the apparatus of Figure 3.

Referring firstly to Figure 1, an active noise reduction apparatus is shown for cancelling noise from a repetitive source such as an internal combustion engine 1. Noise from the engine 1 is cancelled by means of cancellation noise produced by a loudspeaker 2 driven by a controller 3. The difference between the noise from the engine 1 and the cancellation noise 2 is detected as an error signal by means of a microphone 4 and the error signal is applied in a feedback loop to the controller so as to control the cancellation noise produced by the loudspeaker in a manner to minimise the error signal.

The controller also receives a synchronisation signal syn from the engine 1 indicative of its fundamental frequency. The synchronisation signal syn is typically produced by means of tachometer and thus comprises a train of pulses at a frequency indicative of the engine's fundamental frequency. It will be appreciated that the signal syn will vary as a function of engine

speed and thus permits the controller the track the speed variations.

The apparatus operates in the frequency domain i.e. cancellation is carried out for a particular frequency harmonic of the signal syn. In practice, cancellation is carried out at a plurality of harmonics so as to achieve cancellation over a broad frequency band. However, for the purposes of this discussion a single harmonic will be considered.

Referring now to Figure 2, in the case of constant repetitive noise from the engine 1, the controller 3 produces an output signal $\overline{C}$ which is received at the microphone 4 after having been modified according to a transfer function $\overline{H}$ dependent upon characteristics of the loudspeaker 2, the microphone 4 and the acoustic environment between the loudspeaker and the microphone. The noise $\overline{N}$ from the engine is for the purpose of this initial discussion assumed to be constant.

The error signal $\overline{E}$ produced by the microphone 4 can thus be expressed as follows:

$$\bar{E} = \bar{C}\bar{H} + \bar{N} \qquad (1)$$

It will be appreciated that since all the variables expressed in equation (1) represent wave functions, they are actually complex numbers of the form:

$$y = a + ib \text{ where } i = \sqrt{-1} \qquad (2)$$

In use of the apparatus, the error signal $\bar{E}$ is successively sampled at a rate selected to be a predetermined harmonic of the synchronisation signal syn, and a number of successive updates of the error signal are thereby formed.

The error signal for successive updates, n-1, n, n+1 will now be considered for a single harmonic.

For the nth update:

$$\bar{E}_n = \bar{C}_n \bar{H} + \bar{N} \qquad (3)$$

For the n-1th update:

$$\bar{E}_{n-1} = \bar{C}_{n-1}\,\bar{H} + \bar{N} \tag{4}$$

For the n+1th update:

$$\bar{E}_{n+1} = \bar{C}_{n+1}\,\bar{H} + \bar{N} \tag{5}$$

Since the noise produced by the engine is repetitive, it is assumed in the following analysis that the noise signal $\bar{N}$ produced by the engine is constant for equations (3), (4) and (5). Similarly, it is initially assumed for the purpose of this analysis that the transfer function $\bar{H}$ does not vary significantly between successive updates.

In order to achieve noise cancellation during the n+1th sample, the controller output $\bar{C}_{n+1}$ should be selected in such a manner that the error signal $\bar{E}_{n+1}$ becomes zero. Setting $\bar{E}_{n+1}$ to zero in equation (5) yields:

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